Peripheral Production of Sigmas in Proton Proton Collisions

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Abstract

The Pomeron, which dominates high energy elastic and diffractive hadronic processes, must be largely gluonic in nature. We use a recent picture of a scalar glueball/sigma system with coupling of the sigma to glue determined from experiment to predict strong peripheral sigma production seen in the p p $\pi^o\pi^o$ final state.

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1 Introduction

Although all known hadrons seem to lie on Regge trajectories, it has long been known that high energy elastic and diffractive processes are not consistent with the meson trajectories [1]. The Pomeron, with the property that $\alpha_P(0) \simeq 1.0$, dominates these high energy processes. Also peripheral processes, which correspond to production of low momentum particles from the Regge trajectory, at high energies are given by the emission of the peripheral particles from the Pomeron. The most important feature of the Pomeron is that it must be gluonic in nature. Thus peripheral production at high energy is given by the coupling of the peripheral particles to the gluonic field.

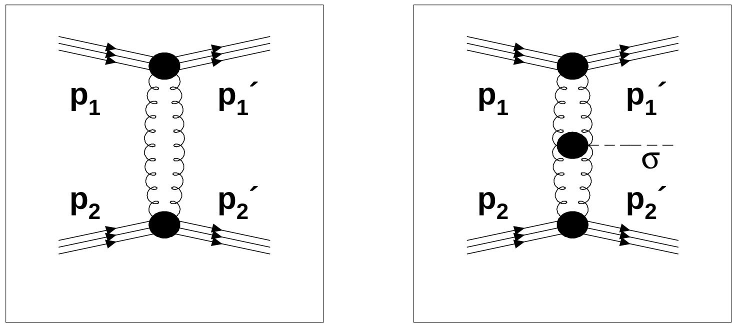
In the present work we study sigma peripheral production in high emergy proton-proton collisions. It is based on the model[2, 3] that there exists a light scalar glueball strongly coupled to the I=0 two-pion system, which we call the glueball/sigma model, and our recent work[4] that this system might lie on the daughter trajectory of the pomeron. The sigma/glueball model was recently proposed[2, 3] based on three observations: 1) at low energies the the scalar-isoscalar $\pi - \pi$ sysem is observed in $\pi - \pi$ scattering[5] to be a Breit-Wigner resonance, which we call the sigma; 2) the sigma seems to dominate scalar glueball decay[6]; and 3) in QCD sum rule calculations we find[2] a light scalar glueball far below the coupled scalar glueball-meson systems which we find correspond to the $f_o(1370)$ and $f_o(1500)$. Our proposed glueball/sigma resonance is a coupled-channel glueball-2π system with a mass and width both about 400 MeV. With this picture it was predicted[3] that there will be found a large branching ratio for the decay of the $P_{11}(1440)$ baryon resonance to a sigma and a nucleon.

In our earlier work[4] we showed that the coupling of the pomeron to the nucleon can be predicted using the glueball sigma model with no free parameters, and that this coupling agrees within expected errors with a phenomenological Pomeron exchange model[7] that is consistent with many high energy experiments. Also, recent work suggests[8] that the $\xi(2230)$, if it turns out to be a tensor glueball, might lie on the Pomeron itself. The present work, however does not make use of any model of the Pomeron. It only uses the fact that the pomeron is gluonic in nature and the glueball/sigma picture of Ref [3]. From this we derive the cross section for peripheral production of $\pi^o\pi^o$ through the glueball/sigma resonance in high energy pp scattering. We find a large branching ratio that can be tested in experiment.

2 Sigma Peripheral Production

As depicted in Fig. 1a, the form of the elastic proton-proton scattering amplitiude with Pomeron exchange is given by

$$A^{pp} \quad = \quad V(t) D^P(t,s) V(t), \tag{1}$$



(a) (b)

Figure 1: a)Elastic p-p scattering, b) peripheral production with Pomeron exchange.

where V is the vertex function given by the Pomeron residue and D^P is the Pomeron propagator. We write this propagator as

$$D^P(q) \quad = \quad \int d^4x e^{iq\cdot x} < 0|T[[G(x)G(x)][G(0)G(0)]]|0 >, \tag{2}$$

where [G(x)G(x)] is a symbolic form for the current of the Pomeron. With a similar notation the amplitude for the peripheral production of $\sigma \rightarrow \pi\pi$ as shown in Fig. 1b is given by

$$A^{pp\sigma} \quad = \quad V(t)D^P_\sigma(t,s)V(t), \tag{3}$$

where D$^P_\sigma$ is the propagator of the exchanged Pomeron coupled to a σ, which decays to the I=0 2π resonance. Of course, the cross section of the diffractive producton process depends on the momentum transfers to the two interacting nucleons, t_1 and t_2, which are different from the momentum transfer, t, for elastic scattering. However, since we are discussing sigma peripheral production, the sigma meson carries a very small momentm momentum

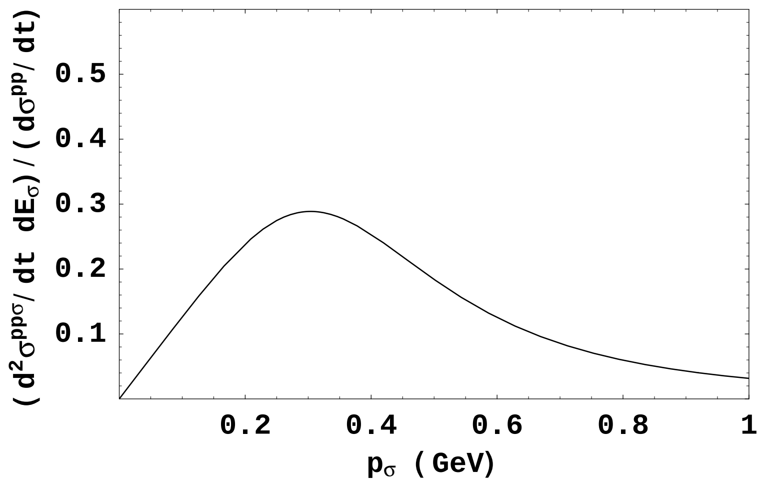


Figure 2: Ratio of differential cross sections of $pp \to pp\sigma$ process to elastic $pp \to pp$ process.

p_σ. Therefore to a very good approximation it follows that $t_1 \simeq t_2 \simeq t$. Note that our calculations are for 50 GeV protons and the sigma momentum is of the order of 0.3 GeV.

Using the external field method with the sigma treated as an external field we write this propagator as

$$D^P_\sigma(q) \;=\; \int d^4x e^{iq\cdot x} < 0|T[[G(x)G(x)][G(0)G(0)]]_\sigma|0 > . \tag{4}$$

Assuming factorization, we use $[[G(x)G(x)][G(0)G(0)]]_\sigma \simeq [G(x)G(x)][G(0)G(0)]_\sigma$. For low-momentum sigmas we neglect the additional form factor for the sigma-gluonic coupling, since it is approximately unity. This gives

$$D^P_\sigma(t, p_\sigma) \;=\; g_\sigma G_\sigma(p_\sigma) D^P(t). \tag{5}$$

In Eq.(5) g_σ is the σ-gluon coupling constant derived in Ref [3] and G_σ is the Breit-Wigner resonance propagator of the sigma. Introducing the appropriate phase space factors we find from Eqs.(1, 3, and 5) the relationship

$$\frac{d^2\sigma^{pp\sigma}/dtdE_\sigma}{d\sigma^{pp}/dt} \;=\; \frac{g^2_\sigma p_\sigma}{2\pi^2(p^4_\sigma + M^2_\sigma \Gamma^2_\sigma)}, \tag{6}$$

where we have included the fact that both gluons can radiate sigmas. The results for the ratio of cross sections in the center of mass frame are shown in Fig. 2.

For comparison with experiment we rewrite our results in terms of the σ rapidity distribution which is a function of the transverse momentum of the σ. With the standard definition the rapidity of the σ and the σ energy are given by

$$y \;=\; tanh^{-1}(\frac{p_{\sigma z}}{E_\sigma}), \tag{7}$$

$$E_\sigma \;=\; \sqrt{m^2_\sigma + p^2_{\sigma\perp}} cosh(y), \tag{8}$$

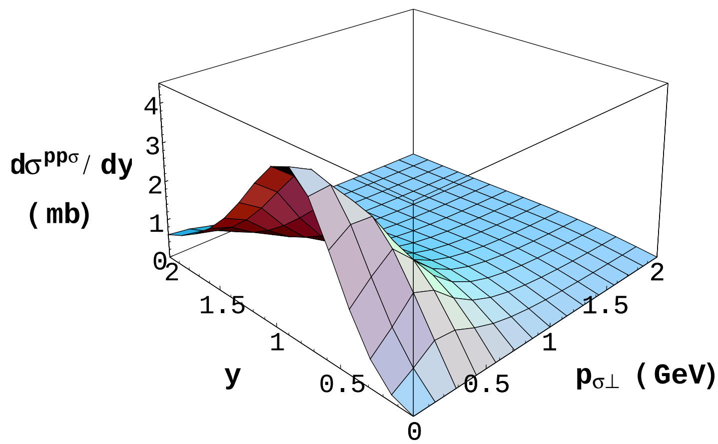


Figure 3: Rapidity and transverse momentum distributiion for sigma production.

where $p_{\sigma\perp}^2 = \sqrt{p_x^2 + p_y^2}$ is the transverse momentum of the σ. Using the approximation that the t variable is the same as for elastic p-p scattering for peripheral production, as explained above, we integrate over the t variable to obtain from Eq.(6)

$$\frac{d\sigma^{pp\sigma}}{dy} = \sigma_{tot}^{pp} \frac{g_\sigma^2}{2\pi^2} \frac{\sqrt{(m_\sigma^2 + p_{\sigma\perp}^2)((m_\sigma^2 + p_{\sigma\perp}^2)cosh^2 y - m_\sigma^2)}}{((m_\sigma^2 + p_{\sigma\perp}^2)cosh^2 y - m_\sigma^2)^2 + m_\sigma^2 \Gamma_\sigma^2} sinh(y). \tag{9}$$

Using the experimental fit to the total elastic p-p cross section at high energy[9], $\sigma_{tot}^{pp} = 21.70 s^{0.0808} + 56.08 s^{-0.4525}$ mb, which is similar to the fit obtained with the Pomeron model of Ref. [7], we obtain the results shown in Fig. 3.

As seen in Fig. 3, in our model the cross section for peripheral production near y = 1.0 and low momentum transfer is quite large, about 2 mb. Note that the charged $\pi^+\pi^-$ channel might not be as satisfactory because of the ρ-meson background from processes at the nucleon vertices, which makes the interpretation of experiment more difficult.

3 Conclusions

We have derived the cross section for diffractive sigma production in high energy proton-proton collisions. By mapping out the low-energy spectrum of the two π_os one will find the sigma resonance if this glueball/sigma model is correct. If so, the production of sigmas can be used as a signal for glueballs and hybrids as well as the Pomeron.

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